QoS-Aware Live IPTV Streaming Over Wireless Multi-hop Networks

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Editorial

The strongly increased performance of IP based networks – in particular during the past decade – meanwhile allows Telecoms and other service providers to offer services with real-time requirements at an acceptable level of quality-of-service (QoS). Voice transmission via the Internet (Voice over IP or VoIP for short) represents an important example of a real-time service which is widely used nowadays. However, also services which require a data rate significantly higher than VoIP are getting more and more important such as the transmission of TV programs via the Internet (by means of IPTV services). As opposed to the traditional way of providing TV programs (e.g. using satellite, cable TV or terrestrial wireless transmissions) by means of broadcasting the TV channels, the original communication protocols of the Internet have been conceived for communications between two partners (so-called point-to-point communication). Though point-to-point communication is still an appropriate model for a phone call between two persons, communication using this principle typically will overload the sender (as well as the network used) if this sender has to distribute the same information to a possibly very large number of receivers as it is the case when providing TV programs. On the other hand, broadcasting information via large portions of the Internet is also infeasible because this would imply the flooding of the networks involved. A compromise between point-to-point communication and broadcasting is offered by multicast communication, in which case a sender will transmit the same information to a group of receivers (which may dynamically vary). In multicast communications, data is transmitted only once if the paths to multiple receivers use overlapping links. Typically, multicast will be indispensable for establishing IPTV systems and the assessment of its usefulness is representing an important scientific challenge, which was one of the motivations for the author of this thesis.

IPTV systems can be offered by means of different kinds of access networks providing access to the Internet. Currently, IPTV services are available mostly via DSL access networks, but usage of wireless access networks (such as WiMAX, LTE) is becoming increasingly relevant. In this context, too, Alireza Abdollahpouri is providing significant scientific contributions, because his studies mainly focus on access networks based on WiMAX, where he does not limit his investigations to single-hop configurations but he also takes into account multi-hop configurations with tree-topologies.

In this publication – representing the PhD thesis of the author – a variety of results have been elaborated which are theoretically well-founded but, at the same time, are also very relevant for practical use in such areas as dimensioning of (IPTV) systems, service availability analysis and improvement, measurement-based IPTV user modeling and characterization, assessment and improvement of quality-of-experience (QoE) for IPTV services.

In particular, the thesis comprises

- new measures (called 'multicast gain'), which allow one to assess the usage of multicast versus unicast, both, for wired and for wireless links in networks;

- realistic models to characterize the behavior of IPTV users;

- methods to calculate the overhead resulting from multicasting and unicasting TV channels in WiMAX based IPTV systems;

- algorithms to reduce the channel switching delay in IPTV systems with users zapping channels frequently.

This innovative research report should be a valuable source of information to researchers, developers, Internet Service Providers (ISPs), and also to (post-) graduate students who are interested in the design, analysis, assessment, construction and/or installation of efficient and highly available IPTV systems with WiMAX-based access networks.

Hamburg, in August 2012 Bernd E. Wolfinger

Abstract

New generation which have grown up with Internet and interactive gaming, are no longer satisfied with traditional one-way broadcasting of TV programs. The paradigm shift from push-based media broadcasting to pull-based media streaming has been started in recent years and will be accelerated in the next few years. Internet Protocol Television (IPTV) is a good example to illustrate this claim.

IPTV describes a mechanism for transporting TV streams encapsulated in IP packets using networking protocols and tries to offer more interactivity and more control over the content. When offered via wireless technologies, IPTV can pave the way for quad-play in next generation networks. However, the stringent QoS requirements of IPTV streams are very hard to achieve in wireless networks. This is mainly related to the natural characteristics of wireless environments, such as frequent packet loss, vulnerability to physical factors and fluctuations in channel condition. The problem becomes even worse in multi-hop wireless networks.

WiMAX as one of the 4G candidates has several outstanding features that make it an ideal candidate to deliver IPTV services to fixed and mobile subscribers.

In this thesis, we investigate some of the challenges of IPTV transmission, mainly in wireless networks. The type of wireless networks which will be covered by this thesis is based on OFDMA-based WiMAX networks. In particular, we focus on the following aspects: the efficiency of multicasting, modeling the behavior of IPTV users, capacity evaluation and effects of overhead in WiMAX networks, and reducing channel switching delay. The objectives are related to each other and each objective is investigated in a dedicated chapter.

Zusammenfassung

Die jüngste Generation, welche mit dem Internet und interaktiven Spielen aufgewachsen ist, ist nicht mehr mit der traditionellen Einweg-Ausstrahlung von TV-Programmen zufrieden. Der Paradigmenwechsel von der Bereitstellung von TV-Programmen im Rundsendebetrieb hin zur bedarfsabhängigen Auslieferung der Programme hat bereits in den letzten Jahren begonnen und wird in den kommenden Jahren weiter ansteigen. Internet Protocol Television (IPTV) ist ein gutes Beispiel, um diese Behauptung zu untermauern.

IPTV ist ein Mechanismus für den Transport von TV-Strömen, gekapselt in IP-Paketen, unter Nutzung von Netzwerkprotokollen, um auf diesem Weg mehr Interaktivität und Kontrolle über die Inhalte zu erreichen. Wenn dies über Drahtlos-Technologien realisiert wird, dann kann IPTV den Weg für 'Quadruple Play' (d.h. das Zusammenwachsen von Festnetz, Fernsehen, Breitband und Mobilfunk auf Basis der IP-Technik) in Netzen der nächsten Generation ebnen. Dies bezieht sich hauptsächlich auf natürliche Charakteristika von Drahtlos-Umgebungen, wo häufiger Paketverlust, Anfälligkeit gegenüber physischen Faktoren und Fluktuationen der Übertragungsqualität im Kanal auftreten. Dieses Problem verschärft sich noch in 'Multi-Hop'-Drahtlosnetzen.

WiMAX, als einer der wichtigsten Standards für Mobilfunknetze der 4. Generation, verfügt über zahlreiche besondere Merkmale, die es zu einem idealen Kandidaten machen, um IPTV-Dienste für Festnetz- und Mobilfunkabonnenten zur Verfügung zu stellen.

In dieser Arbeit untersuchen wir Herausforderungen der IPTV-Übertragung, insbesondere in drahtlosen Netzen. Diese Arbeit behandelt OFDMA-basierte WiMAX-Netze, wobei wir besonderen Fokus auf folgende Aspekte legen: die Effizienz von Multicast, die Modellierung des Verhaltens von IPTV-Nutzern, Kapazitätsbewertung und Auswirkungen des Overheads in WiMAX-Netzen sowie die Verringerung der Kanalumschaltzeiten. Diese Ziele stehen miteinander in Relation und jedes Ziel wird in einem eigenen Kapitel untersucht.

Acknowledgement

This thesis is a result of not only the efforts of my work, but also the guidance, support, and love from many people to whom I am indebted.

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Finally, I would like to thank all those who frequently asked “how is your thesis going?”

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List of Acronyms

3GPP: Third Generation Partnership Project
4G: Fourth Generation of cellular wireless standards
AAA: Authentication, Authorization and Accounting
AAS: Advances Antenna Systems
AMC: Adaptive Modulation and Coding
AP: Access Point
ARQ: Automatic Repeat reQuest
ASN: Access Service Network
ASN-GW: Access Service Network Gateway
AVC: Advanced Video Coding
AZ: Access Zone
BE: Best Effort
BL: Base Layer
BPSK: Binary Phase Shift Key
BR: Bandwidth Request
BRAS: Broadband Remote Access Server
BS: Base Station
BSID: Base Station Identifier
BTV: Broadband TV
CA: Conditional Access
CAT: Conditional Access Table
CBP: Call Blocking Probability
CBR: Constant Bit Rate
CDF: Cumulative Distribution Function
CID: Connection Identifier
CIF: Common Intermediate Format
CQICH: Channel Quality Indicator Channel
CRC: Cyclic Redundancy Check
CS: Convergence Sub-layer
DCD: Downlink Channel Descriptor
DiffServ: Differentiated Services
DL: Downlink

DRM: Digital Right Management
DSA: Dynamic Service Addition
DSC: Dynamic Service Change
DSD: Dynamic Service Deletion
DSL: Digital Subscriber Line
DSLAM: DSL Access Multiplexer
DSS: Dynamic Station Selection
DVB-H: Digital Video Broadcasting-Handheld
DVMRP: Distance Vector Multicast Routing Protocol
DVR: Digital Video Recording
EL: Extended Layer
EPG: Electronic Program Guide
ertPS: extended Real-time Polling Service
FCH: Frame Header Control
FDD: Frequency Division Duplex
FDMA: Frequency Division Multiple Access
FFT: Fast Fourier Transform
FIFO: First In First Out
FTTC: Fiber-To-The-Curb
FTTH: Fiber-To-The-Home
FTTP: Fiber-To-The-Premise
FTTx: Fiber-To-The-x
GOP: Group of Pictures
GPS: Global Positioning System
HD: High Definition
HG: Home Gateway
IE: Information Element
IEC: International Electro-technical Commission
IEEE: Institute of Electrical and Electronics Engineers
IETF: Internet Engineering Task Force
IGMP: Internet Group Management Protocol
IP: Internet Protocol
IPTV: Internet Protocol Television
ISI: Inter Symbol Interference
ISO: International Organization of Standards

ITU-T: International Telecommunication Union – Telecommunication Standardization Sector
LOS: Line-of-Sight
LTE: Long Term Evolution
MAC CPS: MAC Common Part Sublayer
MAC: Medium Access Control
MBMS: Multimedia Broadcast Multicast Service
MBS: Multicast Broadcasting Service
MCID: Multicast Connection Identifier
MCS: Modulation and Coding Scheme
MIMO: Multiple-Input Multiple-Output
MLD: Multicast Listener Discovery
MMR: Mobile Multi-hop Relay
MOSPF: Multicast Open Shortest Path First
MPEG: Moving Picture Expert Group
MPEG-TS: Motion Picture Experts Group Transport Stream
MPLS: Multi Protocol Label Switching
MR-BS: Multi-hop Relay Base Station
MS: Mobile Station
nrtPS: Non-Real-Time Polling Service
OFDM: Orthogonal Frequency-Division Multiplexing
OFDMA: Orthogonal Frequency-Division Multiple Access
P2P: Peer-to-Peer
PAT: Program Allocation Table
PCR: Program Clock Reference
PDA: Personal Digital Assistant
PES: Packetized Elementary Stream
PHS: Payload Header Suppression
PID: Program Identifier
PIM: Protocol Independent Multicast
PIP: Picture-In-Picture
PMP: Point to Multi-Point
PMT: Program Map Table
PSI: Program Status Information
PUSC: Partial Usage of Sub-channels
QAM: Quadrature Amplitude Modulation

QCIF: Quarter Common Intermediate Format
QoE: Quality of Experience
QoS: Quality of Service
RS: Relay Station
RSVP: Resource Reservation Protocol
RTG: Receive/Transmit Time Gap
rtPS: Real-time Polling Service
RZ: Relay Zone
SD: Standard Definition
SFID: Service Flow Identifier
SLA: Service Level Agreement
SMP: Semi-Markov Process
SNR: Signal to Noise Ratio
SS: Subscriber Station
STB: Set Top Box
SVC: Scalable Video Coding
TCP: Transmission Control Protocol
TDD: Time Division Duplex
TDM: Time Division Multiplexing
TTG: Transmit/Receive Time Gap
UBA: User Behavior Automata
UDP: User Datagram Protocol
UGS: Unsolicited Grant Services
UL: Uplink
VOD: Video on Demand
VoIP: Voice over IP
VQE: Visual Quality of Experience
WFQ: Weighted Fair Queuing
WiMAX: Worldwide Interoperability for Microwave Access